5
Human impact on degradation processes

5.1 Introduction

In Chapter 4, runoff and erosion were described as sometimes being emergent processes that occurred when the soil structure degraded and critical conditions were met. In this chapter the focus is on human impact and erosion and what to do about it. Positive feedbacks and scale mean that all life has the capacity to change things at different levels of scale. For example, coral produces reefs that transform the coastal marine systems, beavers by constructing dams transform river channel dynamics and termites, and the deposition of eroded soil as dust is a source of nutrients elsewhere. It is the agents of wind and water and the processes of erosion and sediment transport that propagate these effects.

There are two extremes. In degraded areas, the landscape is adapted to human actions and there is little sensitivity; this might also be the case in natural landscapes. Although human actions might change conditions and processes very easily, it depends very much on what is being done and the context. Just the simple presence of people or hunting can trigger changes that lead to erosion by processes such as splash erosion and litter transport. Responses of the ecosystem can be very rapid and critical soil properties can change from day to day or week to week. It was found by Lopez Bermudez (1995), in Medalus field experiments, that annual plants, as well as shrubs, could produce coarse water stable aggregates around themselves that increased the infiltration rate within a few years by an order of magnitude. Although it could take hundreds of years for the soil to resemble its original state, nevertheless soils formed around annual plants transformed the soil structure with fine roots, during their annual cycle, well enough to prevent erosion. The approach of this chapter is to use local field study results to illustrate specific impacts.

Some useful conclusions about soil erosion are that over a period of several hundred or a thousand years most erosion takes place during a relatively short period during a few extreme almost catastrophic events when particular combinations of circumstances existed.

The dryer and more arid the climate, the longer the period between major erosion events. In the Atlantic rain forest of Brazil, virtually no erosion occurred between a catastrophic time about 8000–9000 years ago and the 1800s when coffee was introduced as a crop. In Europe, studies often show that erosion occurred when something happened and that this was usually in the form of some technical innovation in farming, such as the

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introduction of a new crop or an agricultural implement, and extreme rainfall associated with periods of volcanic activity.

Much of land degradation in the past and today began with the development of the iron manufacture in China in about 500 BC. Trees were required for charcoal to manufacture the iron tools and implements for farmers and armies. Today this continues where the remaining large forest areas are being cleared for charcoal and farmland in Brazil to make pig iron for export to China. A major factor for the past prosperity of China was the scientific and organisational capacity of its civil service with respect to agriculture and land and water management.

When erosion occurs, it usually only affects a relatively small area. Ninety per cent of erosion occurs on 5 per cent of the area during a small percentage of the time. Over thousands of years, the actual 5 per cent of the area being affected will change. It is characterized by a cycle in which weathering or deposition leads to the increase thickness of soil until a critical point is reached when conditions change and promote mass movements or erosion. The fact that periods of erosion and instability follow periods of weathering and soil formation can therefore be a consequence of both extrinsic and intrinsic causes.

The organic soil that accumulates on the surface under vegetation has important characteristics that affect both the micro climate and hydrology. It was found in infiltration experiments all over the world that the forest litter or duff can retain sometimes as much as 3 or 4 cm of water, which is used by the vegetation and soil fauna. As a consequence, hydrological processes and temperature are regulated by this layer and there will be more runoff and much less evaporation if it is lost. At the patch scale, the soil surface is exposed to higher temperatures and often there is too much radiation for plant roots to be attracted to the surface. There is less biological activity in the top soil which is hotter and dryer so that negative soil degradation pathways occur and surface seals develop. Surface seals can also be favoured by the accumulation of dust that contains swelling clays or by sodium. As water is the medium in which nutrients are transported, this also has a large impact on plant growth.

5.2 Soil erosion processes

Soil particles are moved and transported by rainfall and flowing water but even more so by ants, worms, termites and by cultivation, trampling and land levelling. All of these have been extensively measured and studied.

A characteristic feature of soil erosion processes are thresholds: if conditions stay within a certain range, a critical soil erosion process might not occur and there will be no immediate occurrence. Nevertheless if erosion occurs today, it may be the delayed response of changes that took place tens or even many hundreds of years ago.

Erosion occurs mainly as a result of the following agents and processes:

1 By wind erosion: the wind exerts a force on the soil that affects particles of a specific size (coarse silt and sand) when these are not bound together by organic matter, roots or clay.

2 By rain splash erosion. Rain and hail transport soil particles by splash action. Soil particles are eroded by overland flow if more water falls as rain than can enter the soil.

3 By rill, pipe, tunnel and gully erosion. These are formed by or carry flow that becomes channeled. Shrinking and swelling and tillage can lead to subsurface compaction and above this rills and pipes can form in the soil through subsurface erosion. This kind of erosion can also occur wherever flow from roads, paths or fields is concentrated but it requires suitable sediment. The formation of some gullies and pipes occurs in rocks and soils that are erodible and unstable when wet but hard when dry.

4 By tillage erosion whereby the soil is moved downslope by ploughing.

5 By various farming operations: for example, soil is removed in root crops.

6 By trampling by animals and humans.

Figure 5.1, shows the impact of acid sulphate mine waste and mine drainage water. The extensive area affected near Santo Domingo can be seen on Google Earth.

5.2.1 Erodibility

Erodibility is a useful term used to describe the intrinsic sensitivity of the soil to erosional forces that are described as having erosivity. The erosivity of the rain is related to its intensity, drop-size, chemical content and energy and momentum of falling water drops.

The pattern of erosion on agricultural land is frequently explained in terms of the factors that influence it. These are the energy of the rainfall and runoff (erosivity), the erodibility or sensitivity of the soil to erosion, slope conditions, and the vegetation cover and protection provided by crops and also by soil management. Figure 5.2 was taken about one hour after the start of rainfall and about 20 minutes after the start of overland

Figure 5.1 This slide from the Alentejo (Portugal) shows the impact of acid mine water leaking from a drainage pipe that makes the land toxic so that plants can not grow (Credit: Anton Imeson).

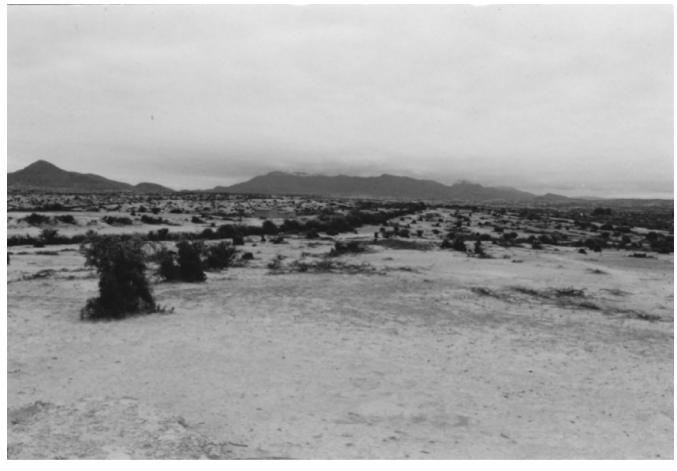
Figure 5.2 Taken at the start of runoff during a rainstorm in Habin Province, China. Note the dispersion. Shallow proto rills are starting to form and they act as drains (Credit: Anton Imeson).

flow, at the top of the slope and field. The runoff is just starting to develop shallow rills. The clay rich soil is relatively strongly aggregated when dry but clay dispersion is taking place where there are large rain drop impacts.

The term erodibility describes the intrinsic ability of a soil to resist erosion. If all of the water can infiltrate into the soil (on sand), if the land is flat, the soil has very stable aggregates resulting from specific types of clay or organic matter, and if it has many stones, accelerated erosion by water is usually limited. A stable and porous soil structure often develops under growing plants and this can make erosion very unlikely during most years. Soil organisms, in creating a habitat for themselves, bind the soil with polysaccharides and roots and increase the resilience. In silty soils, animals are very important in creating pore spaces. High rates of erosion are often correlated with low levels of organic matter but the real problem is the destruction and poisoning of the soil ecosystem and the effects of compaction. In this sense, when erosion does occur, it is a reflection of the degradation of the soil structure and an indicator of desertification.

5.3 Response of soil structure to cultivation and farming

When land is converted from forest, strong water retaining surface soil may persist for many years. Soil degradation can be consequence of many different processes and it depends very much on management. In Figure 5.3, it is possible to see the more or less derelict land left as a consequence of exposing the erodible subsoil in which pipes and tunnels could develop. The land and soil surface when the soil was farmed is present at a few places elsewhere. The extent of degraded areas such as in Figure 5.4 are very



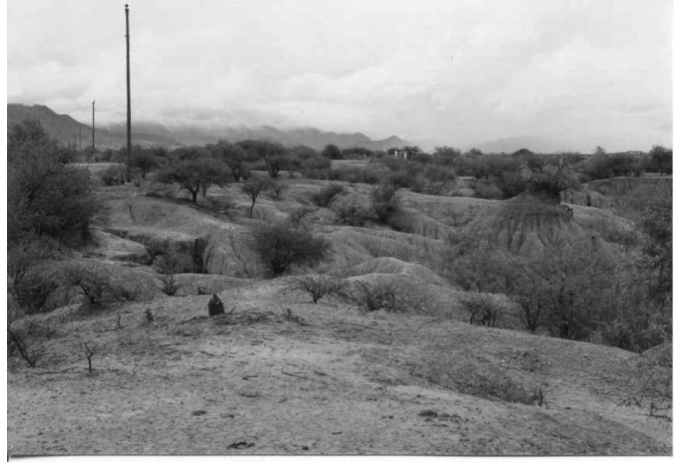


Figure 5.3 and Figure 5.4 Areas with highly erodible soils near Tarije in Bolivia that became degraded and abandoned. These surfaces are the former sub soil horizons after perhaps one or two metres of soil has been eroded since European settlement (Credit: Anton Imeson).

great as are the consequences for the hydrological processes and functions. Figure 5.5 shows similar erosion processes at a construction site, which was not completed because the properties could not be sold.

That soil degradation can occur on different soils as a result of cultivation is a subject that has received much attention in soil physics and agriculture. In many parts of the world, experiments have highlighted a number of key processes and impacts. The organic matter content decreases as well as the characteristics of the soil structure that create problems. In a keynote paper, Dalal and Mayer (1987) described and postulated an exponential decrease in time to a steady state in the organic matter content of soil used for farming after forest removal.

Figure 5.5 Soil erosion on highly erodible marls used as a construction site in on an area of badlands, Murcia Spain (Credit: Anton Imeson).

The scientists at the Queensland Wheat Research Institute in Australia have undertaken many studies that help them understand better the structural degradation that is occurring on their highly clayey soils known as **vertisols**. Similar or somewhat problems on clay soils have been investigated in many other areas under comparable conditions, for example in North Israel and the USA, but they also occur on reclaimed soils in the Ijsellmer in Holland.

One of the findings of Cook *et al*. (1992) at Toowoomba was that they could predict the saturated hydraulic conductivity (permeability) of the soil from the dispersed silt + clay contents, which are easy to measure. The hydraulic conductivity and dispersion are both affected by how clay behaves and this is influenced by the percentage of exchangeable sodium in the soil (ESP). Stones or rock fragments (Figure 5.6) tend to be removed from the soil by farmers because they are thought to reduce the volume of soil for plants and make cultivation difficult. On the other hand they have been shown to have very many positive effects, especially in arid areas. They accumulate because of many processes ranging from frost action, to kicking by animals. Under rocks there is often a higher permeability and organic matter content because it is a preferred habitat for soil animals.

The ESP was highest at the soil surface because of evaporation and it increased steadily with the length from 0 to 64 years. Nevertheless, these were initially also quite high at between about two and four years. This accumulation is a relatively slow process that at some time will trigger a change of state in terms of soil behaviour.

Soil erodibility and its seasonality in Spain

An important conclusion from section 5.3 is that times of biological activity in the soil are favourable for the formation and stabilization of soil aggregates. Seasonal contrasts in Continental areas can produce periods that are alternatively favourable and unfavourable

Figure 5.6 Stones can be very favourable because they can armour the surface, protect the fine particles from erosion and encourage infiltration (Credit: Anton Imeson).

to biological activity and soil stability. Garcia Alvarez and Ibanez (1994) have looked at the influence of crops and climate on the processes occurring at times that are favourable, that is, Spring, and Autumn, when it is difficult for biological activity to take place. What is unfavourable is the rapid alteration of hot and cold or wet and dry conditions that occur because of irregular rainfall or alternations of hot and cold conditions.

At Gualdalajara in Central Spain, Garcia Alvarez and Ibanez measured the enzyme activity in different soils to establish different impacts. An evergreen oak stand was used as a reference for the natural vegetation. In this they found a clear stratification with more intensity near the surface. In the shrub vegetation and cereal crops, the stratification disappears. In cereals areas, there are fewer microorganisms, particularly actinomycites and fungi. Farming reduces the density of microorganisms. Their results suggested that farming reduces the catalytic capacity of the soil. What they concluded is that there is a loss in the capacity for the soil to self organize and that this increases with the degree of human impact.

They explain that unfavourable conditions in the soil in the Autumn produce conditions in which there is a release of nutrients and an opportunity to exploit these resources. The release of nutrients is more beneficial in the Spring when there is a greater enzymic activity. In Figure 5.7 a field site is shown where continuous measurements were made of soil moisture and temperature, and the evolution of the soil structure for about 6 years . The results were published in many papers by Calvo and colleagues at the Department of Geography in Valencia. In this area of about 300 mm of annual rainfall there are many worms and snails under the Stipa plants that can be seen. Figure 5.8a shows a Gerlach runoff collection device. Figure 5.8b, a worm that consumes the *Stipa* roots which extend several meters into cracks in the limestone rocks.

Figure 5.9 gives information about the erosion rates in Spain as measured at different scales. In areas such as Figure 5.7, they are currently very low because of the limited human activities.

(a) (b)

Figure 5.7 and 5.8 (a and b) Part of the ERMES target area in the near Benidorm being investigated by Calvo and associates as a study of processes along a climatological gradient in Alicante.

5.4 Gully erosion

The term gully is used to describe several different forms of linear erosion. They may be V or U shaped and may be formed as a consequence of many different circumstances.

For many reasons gullies are not located randomly throughout the world but instead are concentrated in certain regions. Some areas may be predisposed to gully erosion for geomorphologic reasons related to base level changes such as recent faulting or mass

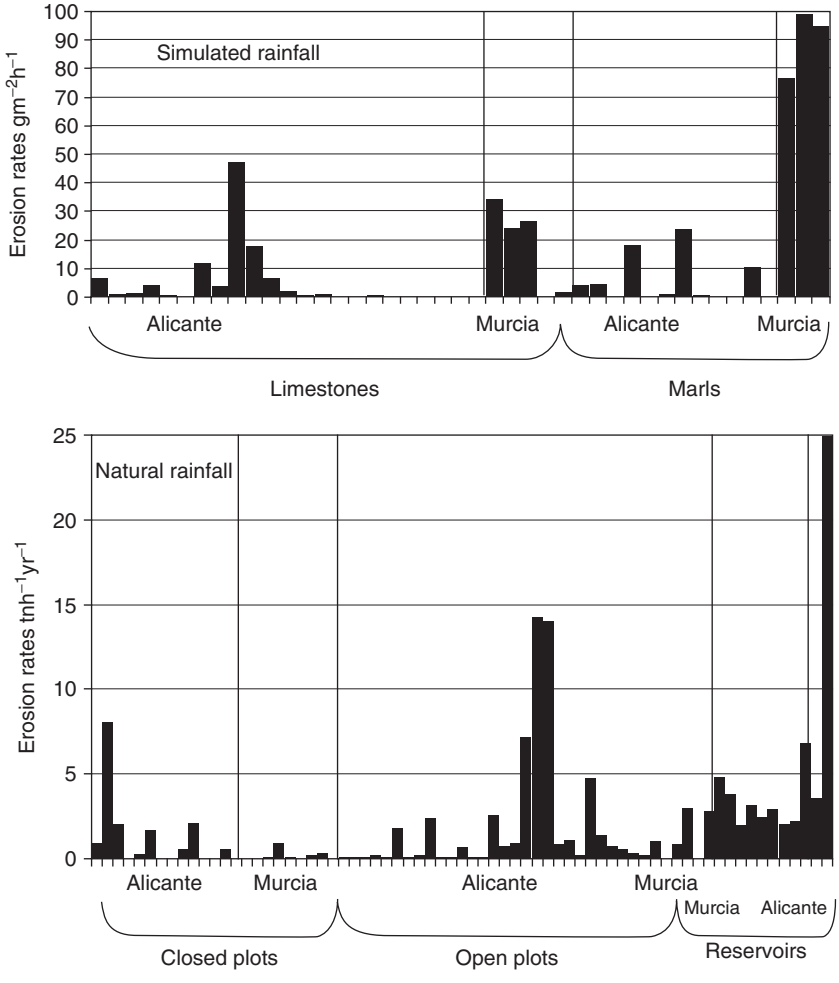


Figure 5.9 Erosion rates from studies done in the areas of Alicante and Murcia since the late 1980s by different research groups. Different methodologies are used, classified as rainfall simulation experiments (above) and data collected at different scales under natural rain (bottom graph). (The data presented are derived from Bautista *et al.*, 1996, 1999; Boix *et al.*, 1994, 1998; Bouma and Imeson, 2000; Calvo-Cases *et al.*, 1991, 2003; Castillo *et al.*, 1997; Cerdà *et al.*, 1995, Cerdà and Navarro, 1997; Cerdà, 1993, 2001; Imeson *et al.*, 1998; Martínez-Mena *et al.*, 2001, 2002; Llovet *et al.*, 1994; López-Bermúdez *et al.*, 1998; Verstraeten *et al.*, 2003; Sánchez *et al.*, 1994). Erosion rates in Alicante and Murcia (Spain). An overview of results, methods and scales of study of the last two decades.

(Authors: Carolina Boix-Fayos1, Martínez-Mena, M.1, Calvo-Cases, A.2, Castillo, V.1 From Scape).

movements. Other areas of gully erosion are confined to sediments having particular material characteristics. A specific concentration of gullies is also present in sub-humid semi-arid or even desert areas where they are associated with dispersive sediments and regoliths. This category of gully is highly sensitive to environmental change. Although gully erosion is often associated with various human impacts or interventions, gully erosion has a very long history. For example, in Natal, paleo-gullies contain datable materials that suggest ages that go back to at least 200 000 BP. There are several feature of gullies formed in dispersive materials that make them particularly sensitive to climate change. One reason is that because the erodibility of the weathered deposits is high, the mechanical energy required to evacuate sediment from gully channels is minimal. Gully erosion is nevertheless sensitive to the way precipitation influences the processes of gully side wall erosion and piping. Most gullies are enlarged by a process of headcut retreat that occurs during periods of growth.

Gullies found in dispersive materials have a number of common features with respect to where they occur, the erosion processes, how they respond to human activity, and relations with hydrology. Gully erosion is particularly severe following the clear cutting of pristine forest and its use for cash crops in areas where there are thick sensitive layers of regolith (weathered rock). Darwin in his diaries described many such areas in South America but they are very common throughout the tropics. What gully initiation requires is suitable erodible sediments. When these are exposed on the surface as in Figure 5.10 this type of process can be observed. The material being eroded in Figure 5.10 is not in situ. It is likely to be a colluvial deposited as a consequence of the first forest cleatances and land use practices that resulted in the erosion of the red Mediterranean soils that were then present and which no longer exist.

Figure 5.10 Erosion processes in Valencian orange fields as a consequence of the managment practices. Photo Cerda 2011.

5.5 Grazing and erosion

The domestication of livestock and herding of animals is an ancient activity that has a number of influences on land degradation and erosion. Animals can make the soil compact and encourage concentrated runoff. Saturated or Horton (1945) overland flow and erosion take place (explained in more detail later in this chapter) and at the same time that animals trample and displace rocks and stones downslope and they consume or destroy vegetation that is protecting the soil. But animals can also have positive impacts that reduce runoff, for example by adding nutrients that promote plant growth and which reduce runoff. Research is very difficult because the interactions and feedbacks between plants–animals–erosion occur over tens or even hundreds of years, and they involve the use of fire as a means of improving plant palatability and also changes in management practice. In some cases, erosion features in areas of present day high grazing intensity are the result of erosion perhaps many tens or hundreds of years ago and cannot be attributed to today's flocks.

The concept of overgrazing means that farmers realize that they will damage the land if they keep more livestock than the carrying capacity of the land warrants. Traditionally, the livestock numbers kept by pastoralists would be related in very complex ways to the availability of pasture and grazing opportunities. However, similarly to today, there would always be social or land use policy pressures on pastoralists to manage their livestock in a way that at times risked erosion.

In Europe livestock was traditionally a symbol of wealth for the old Germanic and Celtic tribes so they would probably maintain stocking rates at the maximum.

Research by Trimble and Mendel (1995) has shown that, where cattle range freely, the cow is perhaps the most important agent of erosion in the world today. Using areas for cattle that were traditionally used for raising sheep or pigs is a major reason for much soil erosion in parts of the Alentejo (Roxo 2009). In many tropical areas, such as those in Bolivia, cows graze very steep slopes and destroy the vegetation and displace large volumes of earth downslope in their search for food. Figure 5.11 show the landscape near Omalus in Crete, that was a research area of an ecosystem degradation study carried out along a climatological gradient from Omalus to the coast. Figure 5.11a, is an overview of the Omalus depression which is circular so that it is possible to look at the relationship between grazing and aspect. Most grazing pressure then seemed to be the west facing slopes, that were preferred. Figure 5.11b shows the animals kicking stones downslope, and this is an extremely important impact. The vegetation in the area provides too little feed for the number of animals, so there is relatively much trampling along pathways. Goats and sheep play an important role in traditional farming but there is great pressure on common and public land.

This is partly because of the heavy weight of the cow and the impact of trampling and displacing soil downslope. The occurrence of soil erosion processes induced by most grazing animals is related to the intensity of the trampling and this is connected to the location of so-called watering and gathering points where animals congregate as well as the location of fences.

The huge increase in livestock (particularly pigs) but also sheep and beef has its impact in the areas where the feed is produced. The production of irrigated livestock feeds in the dry Mediterranean regions is a major factor in the decline of the local groundwater. The overstocking and soil degradation is only possible because of the importing of feed from

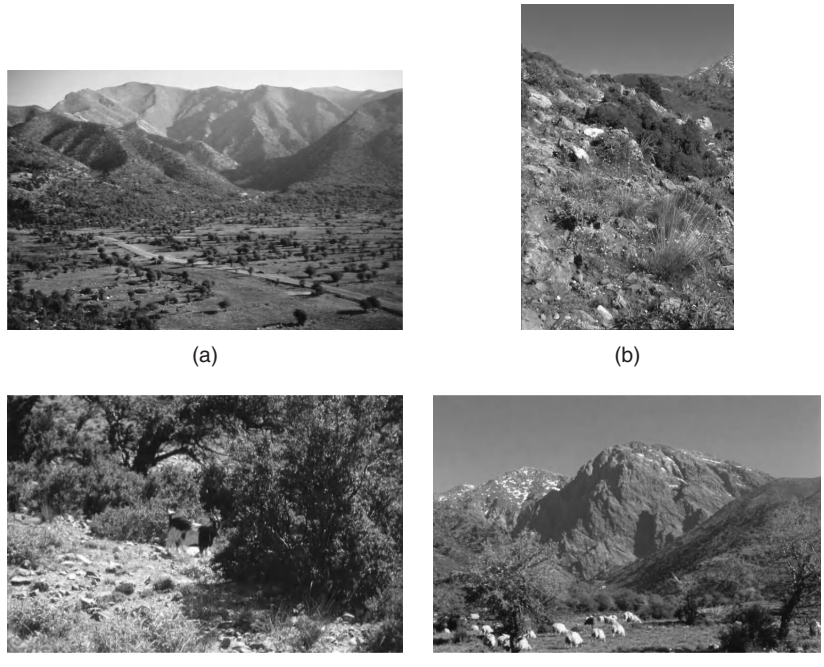


Figure 5.11a, b, c and d These show the ERMES field site at Omalus, Crete at the time of the research. This area was formerly forested. Photo b shows the impact of fire and grazing on the vegetation. As the vegetation recovers after a fire, the area on which the goats can walk becomes smaller (Credit: ERMES and Anton Imeson).

other European countries. There is no relationship between the number of livestock and the carrying capacity. This is happening all over Europe, not just in the Mediterranean.

The effluents produced by animals leak into rivers, making the summer low flow discharges of many Mediterranean rivers toxic. The over application of manure has resulted in the degradation of soil structure so that many soils have become much more sensitive to erosion.

In Lesbos in Turkey Govers and Poesen (1998) measured the effect of sheep walking across a hillside on downslope movement of rocks. In Israel Yair (1995 personal communication) showed that grazing animals were responsible for most sediment found at slope foot positions. The erosion in Israel had a beneficial effect because it concentrated sediment at the slope foot where it could be farmed and it reduced the depth of soil on slopes so that there was more rainwater harvesting and infiltration for use downslope.

Xu (2006) reports on the dust sand storms in and around the Ordos Plateau in China and how they are influenced by land use change and desertification. He relates the frequency of dust storms to the area of desertified land at the level of counties. The precipitation in his study area increased from the northwest to the southeast from 150 mm to 400 mm. Most dust comes from fluvio lacustrine deposits and it occurs when the fragile

steppe vegetation is damaged by grazing and cultivation. Xu says that when these stop, the quality of the land improves and erosion also stops.

Grazing and small scale soil surface structure was investigated by Golodets and Boeken (2006) in Israel. They found, in the northern Negev, that moderate grazing had a significant effect on soil structure and vegetation patterns. Grazing increased bare soil and halved the size of vegetation patches on mounds. Even low grazing intensity had significant effects on the spatial heterogeneity of semi arid shrub land. It is known that heavy grazing (Ludwig *et al*. 1977). reduces the size and abundance of shrub patches in the landscape, but the results here show that low grazing also has an impact.

On range lands it was noted by that the authors that where at some locations in Saudi Arabia these had been managed sustainably, these were dominated by highly productive grasses. In most areas, however, livestock was at a level far beyond the carrying capacity. What happens in the Middle East is that camels and goats which are not selective remove many more species than sheep or cattle did, when these can no longer survive. Rangelands also provide fuel for cooking, which is also removed. Nomadic and transhumance grazing systems have benefits.

5.6 The impact of fire on land degradation processes

The relationships between erosion, fire and desertification are paradoxical in the Mediterranean. In 1991 Rubio and Sala (see Rubio *et al*. 1991) organized a workshop that reviewed all of the then current research findings. The surprise conclusion, which still holds today, is that except under special circumstances fire mostly positively improves the ability of a soil to retain water and increases its fertility. Only where soil temperatures exceeded a critical value of about 400–600 degrees did soil erosion increase. Mediterranean forest trees and shrubs have adapted or altered soil properties so that water is usually trapped. These properties (high porosity, water repellent induced rainwater harvesting structures) mean that water remains on the slopes and will not cause erosion, unless the soil is very thin or has had these positive properties damaged by trampling. Where very high rainfall amounts can sometimes occasionally occur, as along the Mediterranean coast in Valencia, then there is a risk of erosion, perhaps once every ten years (Rubio *et al*. 1991). However, normally, the vegetation resprouts and soil properties improve so that three or four years after a fire there is no risk of erosion. But, even when erosion does occur, soil particles are trapped by resprouting vegetation and there is a positive effect. It is the case that following a fire there is less evaporation and organic matter, so there is more water available for resprouting trees.

If fires themselves do not result in erosion, why then does erosion recently often follow a fire? Research has indicated two main reasons. Firstly, there is the professed fear of postfire erosion and the question of the availability of money to protect people from the risk. Instead of fencing off the forest and keeping people out so that the vegetation can recover, soil conservation protection measures are constructed, burnt trees are taken out of the forest and often seedlings are planted. Trampling and soil profile compaction and inversion occur. All of these actions destroy the capacity of the soil to retain water and prevent erosion. Highly erodible B and C horizon material is often exposed on the surface. At the same time, the soil is made bare, runoff is concentrated and very often rill and gully erosion are caused.

The second reason why erosion occurs is that the trees grown in plantations are exotic and have not developed soil properties or a fire hydrology that is adapted to the local conditions.

Another (third) reason is because of grazing. The first plants that grow after the fire are generally rich in nutrients and favoured by sheep and goats. Although there are often regulations that should protect the plants from grazing, in practice they often still get eaten and in the process, the weak soil, which has a fragile week house-of-cards structure, gets trampled.

In conclusion, forests fires and wildfires generally do not usually cause erosion in themselves, so there is no need to panic. What mostly causes erosion are the postfire activities of the community, who are extracting a living and exploiting the situation. Preventing erosion could also be achieved by keeping people off the land and allowing nature to recover.

5.7 Case 1: Blue Ridge Foothills

Ambers *et al*. (2006) present an interesting case study that provides an example of the long-term changes caused by human impact. The region of the Blue Ridge Foothills, central Virginia, suffered severe amounts of gully erosion in the past and the methods that were developed to control gulley erosion are described in the classic paper by Ireland *et al*. (1939) in which they describe and recommend principles for controlling gully erosion that are still being used today. Trimble in 1974 had pointed out the influence that soil conservation had on the sediment dynamics of rivers and he later drew attention to the way in which the magnitude of erosion rates is greatly overestimated in models that lack feedbacks with land use and geomorphological thresholds.

Ambers *et al*. (2006) look at the detailed field evidence at Monument Hill (2006) and concluded that the following happened:

- 1760: Deforestation and agriculture were introduced: the impact was sheet erosion and the aggradation of the river channel. This continued until 1830
- 1830: Gully erosion started and the land was abandoned with perhaps the channelization of the river beds. This continued to about 1865
- 1865: Forest regrowth and soil stabilization. There was a rapid incision of the rivers until about 1900 and the continued growth of the forest until today, when there is some forest thinning.

Ambers *et al*. conclude that this response is typical of the region. They say that sediment production rates averaged 130 tons per hectare per year from 1776 to 1888. The peaks in erosion rates reported by Trimble occurred in 1920 which they say happened because his study area was settled later. The legacy of past agriculture has a really long-term impact on rivers.

What this means at a different scale is illustrated by the next case.

5.8 Case 2: Human impact in the Atlantic States

This area in the USA has been studied by many people. In 1969, Meade (1969) summarized what was known at that time. He writes that human activity had increased the sediment loads in streams draining the Atlantic States since the first European settlers landed. In the Chesapeake Bay region there are records describing the forest clearance and cultivation methods of tobacco which resulted in clear streams becoming muddy and formerly deep harbours filling with sediment washed from upstream farms. According to Meade, in 1950, 2 million tons of sediment was still being deposited each year. Soil conservation measures on land that was formerly eroded have meant that there have been some reductions in sediment loads between 1934 and 1953, but nevertheless vast amounts of sediment were still being delivered to the rivers. But it was not just agriculture but also coal mining in Pennsylvanian rivers that was a cause and at certain locations 10 per cent of the sediment was found to be coal.

Meade also analyses the impact of man on the dissolved material carried by streams and he reports on the measurements of Anderson and Faust (1963). In the Passaic River of New Jersey, in 1963, half of the flow was used for domestic and industrial supplies. Coal mines and agriculture add fertilizers and pesticides so that the situation was chronic. Meade estimates that as a consequence, sediment and dissolved loads are at least four times what they were before European settlers arrived.

Almost twenty years later in 1988 Margareta Jansson (1988) from the University of Uppsala published a global survey of sediment yield. This was one of a series of papers on sediment yields and global variations in erosion rates. The question being asked was how the global variations in sediment yield were being affected under current human influences.

It was found that, as is well known, the size of the drainage basin has a critical role to play and that the amount of sediment output per unit area decreases with size and that the greatest variability within a region is in the output from small catchments. Factors other than climate play a dominant role. Nevertheless, rainfall amount, intensity, snow and temperature and evaporation all play a role. If the river gradients are low, negative outputs can occur, for example in the Yangtze River. Jansson analyses relationships between runoff and sediment discharge and finds that these in fact do not exist, except locally.

5.9 Case 3: Impact of forest logging in California Casper Creek

The importance of roads as sources of sediment

When roads are constructed on sloping land, they profoundly change the hydrology. The nature of these impacts and changes has been given much attention because road building and construction is also a major source of runoff. This has been demonstrated all over the world.

When scientists began to compare the first quantitative measurements on sediment yields and budgets from measurements that were started in about 1970 onwards, it soon

became clear that in many cases most of the sediments were being supplied from roads and tracks and not from the forested slopes.

Examples of this finding came, for example, from studies made by Froehlich and Slupik (1991) in forested catchments in the Carpathians. In the United States, studies in the Pacific North West, by Reid (1981) illustrated this. In virtually all forested catchments, the main sources of flood runoff and sediments were unsurfaced roads and tracks.

Logging in California Casper Creek

A valuable example of the impacts of forests and roads on processes is reported by Rice *et al*. (1979). They studied the response to logging and roads in the South Fork of Casper Creek, in the Jackson State Forest near Fort Bragin California, between 1967 and 1976. It is a classic paired water shed experiment in which two similar drainage basins are compared before during and after treatments. In 1962 the authors say that the age of the forest that was logged was 85 years. During the experiment logging seemed also to trigger a landslide and dam break. The experiment was designed to measure the impact on stream flow peaks and sediment loads. It was expected that the increase in water yield would be small. Like most rivers in the region, most sediment is carried during peak flows.

Between 1963 and 1967, for four years, there was a period of calibration, then between 1968 and 1971, roads were constructed and in 1972 logging began. The experiment therefore first measured the impact of road construction and in the second phase, logging and roads together. Soil erosion rates were measured in large rectangular plots of about 201 metres wide and 322 metres long. Rice *et al*. describe the response to logging as dramatic. Deviations of sediment yield in the South Fork of Casper Creek from the amount predicted from observations in North Fork, 1963 to 1976, were studied. The main changes were that the nature of the sediment supply to the river changes. Before, treatment sediment was described as being supply limited. After treatment, it was dependent on the amount of flow and discharge controlled.

In the discussion, concern about the soil loss is played down. During road construction and logging, little consideration was given to erosion control or control of water. Work was inexpertly done and ephemeral channels used as skidways; furthermore, no regard was had to hydrology or slope stability. The work was considered to have permanently damaged forest productivity for at least 10 to 15 per cent of the area. In evaluating the impact of erosion, Rice *et al*. say this is minimal in relation to the total amount of soil left, but the other functions of the soil that are being lost are not considered.

The impact on water quality was concluded to be a major concern and the existing aquatic systems were unable to maintain themselves with the new runoff regimes and sediment loads.

5.10 Case 4: Karuah Forest, New South Wales, Australia

The effect of clear cutting and road operations is also illustrated by the research of Riley (1984) in New South Wales, but he looked at the impact on the soil permeability and infiltration. He worked in the Karuah Forestry Commission where the relief was 500 metres and the rainfall above 1500 millimetres per year. He investigated the effects of different types of disturbance of the soil which had a 10-centimetre-thick ecto organic A

horizon. He compared uncleared and cleared forest and sites along a road. The road sites were used for the transport of heavy machinery. The soils were the brown and yellow podzollic soils which have a texture contrast (they have been mentioned earlier elsewhere (see Hallsworth *et al*. 1953). The properties, or responses, he measured included the sorptivity (infiltration measurement, also explained elsewhere). This describes the maximum rate at which water can enter the soil and it can be used to calculate ponding times to predict runoff responses.

Riley found that the logging operations reduced the ability of the forest ground surface soil to transmit water and that the greatest reduction was for the roads. His mean values of sorptivity decreased from a range of 275 to 89 to 7.5 mm. On roads, it decreased 100 fold and on the forest soil, three- to five-fold. The saturated hydraulic conductivity decreased eight-fold. His conclusion is that this will and does lead to a large amount of runoff production on roads and the reduction in throughflow to the river.

5.11 Case 5: Afforestation in Spain

This case is different because it is about change to forest, not from forest. The Aleppo Pine (*Pinus halepensis*) afforestation has always been considered as one of the principal strategies for addressing land degradation and it is promoted everywhere, in addition because of the perceived benefits of reducing sediment yields to rivers. The government planted 2.5 million hectares in Spain with this tree and it is said to have increased the tree cover of Spain by 75 per cent. It has colonized extensive areas of abandoned land, and in Alicante, for example, accounts for 90 per cent of the tree cover (Chirono *et al*. 2006). Its distribution is encouraged by fire and is has been planted in both semi-arid areas that had a steppe of shrubland vegetation cover or in the more humid regions of oak forest. In a number of cases, there have been problems because of the impact of the techniques used for preparing the site with bulldozers, and for other reasons, so that the success rates are not always high and the trees have a bonsai appearance. In other cases, where the trees do grow, there are frequent fires and hydrology is disrupted.

An important analysis was reported by Chirono *et al*. (2006) who established plot experiments on trees that had been planted 30 years previously. Their findings were analysed statistically rather than according to processes and they focus on the relationships between forest cover and runoff percentages. Statistically, there is a threshold at about 30 per cent vegetation cover at which a tree cover in general prevents erosion.

The conclusions, for the semi-arid areas near Alicante that they studied, were that the grassland and shrub communities were equally good in reducing runoff and at the same time retaining richness and diversity of species.

5.12 Case 6: Soil erosion impacts in Europe

An overview of historical soil erosion and conservation in Europe is given by Lang and Bork (2006). The consensus is that the areas most affected by erosion are in the Northern Loess Belt and in the Mediterranean region. Mountain and northern regions, with short growing seasons and frost, are also affected by erosion.

In western Europe (e.g. England and western France), most water erosion occurs during the Winter months when soil profiles are saturated and this may be caused by low

intensity storms. Going eastwards, high intensity summer rainfall storms become more important in causing erosion, so that in Central Europe erosion occurs mainly during the Summer (as is also the case in China, much of the USA, in Brazil and Australia). However, rainfall increases with altitude, and the central European, Italian and French mountain areas have frequent erosive summer thunderstorms, that occasionally produce comparable Summer rainfall. The annual variability, however, is high. Land use and management practices in central Europe have had to adapt to high rates of erosion risk.

In northern Europe, most erosion occurs during the Spring period of snowmelt. In areas where the soil freezes in the Winter before it is covered with snow, there tend to be erosion problems in the Spring. In south-eastern Europe, the Carpathian Mountains and the Danube basin have more continental climate conditions, but there is much erosion in the mountains of Romania as a result of forest clearance. However, towards the south-east in the agricultural areas, Summer droughts become more of a problem and steppe-like areas are found.

Limestone and karst areas are very common in the northern Mediterranean region and on the large Mediterranean Islands. Particularly in the mountains of Crete, and in areas of Slovenia, Dalmatia, Greece and Italy, as a result of intensive grazing, there may be rocky desert-like areas that resemble those in China. In Crete, most rainfall occurs in Winter but in some specific areas of the northern Mediterranean it is more evenly distributed throughout the year, or it has a maximum in the Summer. In Spain, there are extensive areas of limestone in south-east and central Spain which are quite humid and which are in many ways comparable with China.

Historical erosion in economically marginal areas

At the end of the last century, many areas of Europe that were agriculturally marginal suffered from land degradation and erosion and there was a subsistence economy and much poverty on occasion. In the Mediterranean area, the population in the rural areas was usually very high. Land use practices and conditions resembled those found in parts of Morocco today. Erosion was often caused by policies put in place by the then governments to achieve national self-sufficiency in wheat or rice production. On the other hand, there were a number of afforestation projects in degraded mountain areas that transformed landscapes. A major feature of the Mediterranean region is the litoralization of the population when people moved to the major cities and the coast. People moved to the coast and cities for social reasons, not just because land degradation had made agriculture unproductive. Figure 5.12 and 5.13, illustrate several paradoxes. This area is in the boreal forest zone where and by normal standards very marginal for most arable crops, especially wheat. After the war the traditional mixed farming in the region was changed and all of the animals were moved away from relatively flat areas that could be converted into large fields. This desire to have agricultural land in Norway is political and cultural. Figure 5.12 illustrates the arable landscape that was created by land levelling and which breaks up the monotony of the endless forest. The perception is that there is too little flat land and that it is worthwhile to increase the cultivable area, for aesthetics and national food security. It is made possible by subsidies but in order for the farmers to receive enough money they are allowed to cultivate slopes that are too steep because there is a shortage of flat land. Figure 5.13 shows the soil erosion plots in Norway being used to quantify erosion models such as the USLE.

Figure 5.12 and Figure 5.13 Erosion from wheat fields in Norway (Credit: SCAPE and Anton Imeson).

It is of special interest that in some areas of Europe (notably France, Spain, Portugal, Belgium, the Netherlands, Germany and Italy) there are records showing the long-term positive impact of afforestation and other soil conservation on the sediment load and erosion of rivers (Ternan *et al* 1996). There are several studies of sediment budgets in catchments of different sizes.

Limestone areas with rocky desertification are very extensive, particularly in Spain, Greece, France and Slovenia. Many limestone areas that were formerly barren and occupied by a large number of farmers are now forested. These provide an example of

how voluntary depopulation can lead to the recovery of ecosystems. In the case of the Mediterranean region, forest fires increase, stimulated by subsidies that provide income.

Provided that human influence is small, erosion is everywhere limited, with the exception of areas that are geomorphologically unstable and affected by tectonic processes and uplift. Similar types of rock weather into similar types of regolith and soil so that the geology and soils can be used as a basis for transferring information between regions. Areas that are similar geomorphologically and hydrogeologically have many processes and conditions that are similar so that soil conservation strategies and approaches in these areas are comparable.

Conclusion

The main drivers of soil degradation and erosion in Europe today are cultural, ethical and financial that result in society accepting practices and habitual behavior that results in actions that deregulate, destroy and ignore the critical processes in the soil and landscape described. Elsewhere, the illegal or legal use of natural vegetation for wood and charcoal and its conversion into land used for palm oil, coffee, sugar and soy, and so on, are carried out in an unsupervised and unmanaged way. People deprived of their natural and economic capital cause land degradation elsewhere and put pressure on resources. Soil erosion and land degradation are affecting many areas in Europe and occur in association with unsustainable agricultural practices, irrigation, fire, salinization, sodicity and overstocking. On site erosion is particularly prevalent in areas with fragile and sensitive soil conditions, such as those that occur in mountains, in areas affected by sodicity and salinity, and in areas where there are repeated forest fires or overgrazing. Areas affected by uplift caused by isostatic uplift and neo-tectonics are sensitive.

However, in virtually all European countries, soil and land degradation have similar causes. The worst examples of erosion problems are usually associated with land levelling and the construction of terraces. Afforestation programmes whereby trees are planted in areas that are too dry or cold are common and these also cause erosion. Most erosion and land degradation is the result, therefore, of government or EU policies that promote land use change or which tolerate land use practices that degrade the soil structure and its capacity to regulate the hydrological processes. Both Norway and Portugal, four thousand kilometres apart, have policies that support and subsidize wheat production in areas that are unsuitable.

5.13 Case 7: Human impact in the Central Cordillera of Columbia

Twenty years ago a project was set up by Van der Hammen and others to describe and record the characteristics of the ecosystems present along a transect in Columbia running from the Ria Magdalena in the east to the River Cauca in the west. This was one of a number of studies in Columbia that were made to establish and describe conditions in areas that were then largely forested but the forest areas were being lost at a very rapid rate. Detailed information about this specific case study can be found in the Imeson and

Vis (1982). The data are interesting because they illustrate and synthesize very clearly many of the relationships described earlier in the present book.

Along the transect, the following altitudinal zones were described by Imeson and Vis at p. 42. The transect crosses:

- The paramo at 3800 to 4700 m.
- The Andean Forest, 2400 to 3800 m.
- The Sub Andean Forest, 1500–2400 m.
- The warm tropical lowland below 1150 m.

Imeson and Vis examine the effects of forest clearance on soil erodibility and soil erosion rates. They state that most of the changes in soil characteristics that affect soil erodibility are related to changes in the soil micro climate. This is exactly the same as in Mediterranean case studies. The insulating effect of the vegetation and litter is eliminated so that the amount of incoming radiation reaching the ground surface increases. The rate of decay of soil organic matter increases considerably. The decreasing loss of organic matter is also caused by the lower rate of net primary production.

5.14 Case 8: Bolivia Tarije

Present-day environmental change and environmental degradation in the Central Andes have been attributed mainly to post-colonial intensification of land use and subsequent population increase (Libermann Cruz and Qayum, 1994). However, the influence of pre-Colombian civilizations cannot be excluded and several authors report overgrazing and erosion processes during Inca times (Baied and Wheeler, and Messerli *et al*., 2000). Moreover, the Central Andes is a tectonically active region which has also been affected by climate change. The Central Andes is, therefore, a relatively dynamic and complex region where the causes of environmental change are difficult to analyse and unravel. The research data were collected in carefully selected target or case study areas in the region around the Central Valley of Tarija, South-Bolivia. This was an ideal location containing the three main types of Central Andes ecosystems within in a relative small area (i.e. sub Andean valley, high Andean plateau (Altiplano) and inter Andean valley). Incorporated into the project objectives was the additional goal of identifying both the degree and causes of land degradation. As long-term monitoring was not feasible and long-term data sets were not available, direct and indirect indicators were used to assess environmental change.

For more detailed investigations, small catchments were selected to study erosion processes at the patch and hill slope scales. Another objective was to relate soil and water quality and vegetation cover with present land uses. By studying the impact of grazing on soil and vegetation properties, the effects of present land use could be evaluated. The main research area in Bolivia is located near the city of Tarija in the south of Bolivia and consists of three distinct ecosystems representative the Central Andes. This includes the sub Andean valleys that lie at the fringe of the eastern ranges where the Andes

are bounded by the Amazon or Chaco basin; the extensive highland Andean plateaux (Altiplano); and the inter Andean valleys that cut through the Altiplano. The climate in the sub Andean valleys ranges from semi-arid (679 mm yr^{-1}) in the centre to semi-humid (1000 mm yr^{-1}) near the mountain front. Winters are characterized by a long dry period of eight months and most precipitation falls in high intensity summer storms. Maximum daily precipitation in summer time in the semi-arid area ranges from 20 to 60 mm. In general, the semi-arid zones are situated at lower altitudes between 1800 and 2000 masl and humidity increases with altitude. Climatic conditions on the highland plateau are semi arid and the yearly average is 298 mm. Precipitation falls in the four summer months with daily maxima ranging from 8 mm to 25 mm. The largest area is situated mostly between 3600 and 3900 masl, except for the mountain peaks that reach altitudes of 4700 masl. In the bottom of the inter Andean valley, the climate is semi-arid and the average annual precipitation is about 320 mm. Maximum daily precipitation amounts range from 5 mm to 45 mm and these occur during intense summer thunderstorms. The inter Andean valleys follow an altitudinal gradient that falls from 3600 masl near the Altiplano to 2600 masl in the valley bottom.

5.15 The sediment load and soil erosion

The sediment load of rivers can provide information about on-site soil erosion. It enables the nature and the sources of sediment to be to some extent identified. Any increase in sediment load can be used to identify the occurrence of erosion caused by polluters. Problems can be identified by the soil conservation service and dealt with. Sediment is a major carrier of phosphates and other chemicals that cause eutrophication. In the long term, the positive impacts of land management may be demonstrated. The slope of the sediment discharge–water discharge rating curve will become less steep and this will be an indication that conditions in the entire catchment are better. The reasons why the sediment load is not ideal are several. Relationships between sediment concentrations and hydrological parameters (precipitation, discharge or peak discharge) are highly variable because of the different processes that influence the supply of sediment to the river, the composition and nature of the sediment (organic matter, size distribution, mineralogy, etc.) and the erosivity and erodibility of the soil). An unknown percentage of the eroded soil will be deposited on the slopes and remain as colluvium. Channel erosion will also contribute much sediment to the river. Paddy fields also retain a large amount of sediment but this is not the case for upland rice. This means that the statistical strength of the relationships will be weak. The accuracy of both discharge and sediment yield measurements is low. This is because much sediment is transported at high flows. The accuracy of runoff measurements is probably no more than 90 per cent and the sediment yield calculations could be easily a factor of 2 to 5 in error.

The USLE, erosion models and sediment yields

As long ago as 1951, Anderson *et al*. established that there were good statistical relationships between erosion as calculated by the USLE and the long-term accumulation of

sediment in reservoirs. Anderson (1962) and many others have established very strong statistical relationships between catchment characteristics, including geology and land use, etc.., so that they could predict erosion. The problem is that relationships change in time as conditions in drainage basins alter. There have been many recent studies in which erosion models, based on the USLE or other models, have been used to predict erosion. Recently an intermodal comparison of erosion models used data supplied by, amongst others, the author, and concluded that the models only worked when utilized by the people who developed them for their own area. There is not enough data on real erosion rates to calibrate most models and they usually exclude important processes. Under ideal conditions (detailed images, trained staff, sufficient budget including for field verification, and calibration), it is possible to use GIS and to estimate erosion and the changes that will occur as a result of management including soil conservation. The question is then which parameters can be entered into the model and how are the processes parametized? It or any model could be used to calculate what the effect of the changes on erosion might be. However, a DTM can be used to model the impact of slope on runoff generation and this is used to obtain a spatial representation of erosion. The advantages of the approach are more in the ability to apply GIS and model scenarios, rather than in any additional accuracy that would be hard to demonstrate as there is no data.

5.16 Monitoring methods to verify impact and management on erosion

There are many alternative approaches to monitoring the reduction in soil erosion that make use of on-site measurements. In considering these, consideration is given to the spatial and temporal scales being considered and also to the different types of processes involved. Sometimes indicators or indexes can be used that have been demonstrated to have value. In Table 5.1, there is an overview of the different erosion processes and of the techniques and methods that are often used to investigate them.

Rainfall simulation experiments are a valuable tool in directly estimating the amount of erosion caused by different rainfall amounts and intensities. Many countries such as Israel, Spain and the USA have made intensive surveys of infiltration and erosion indicators using simulators. These measurements can be used to validate indicators. Another use is to measure and compare soils according to the amount of rainfall needed to cause water to pond on the soil and produce overland flow. They can be used to measure differences in erodibility and to estimate the erodibility (k factor). The USLE ignores many of the processes that result in the delivery of sediment to the river. When monitoring erosion, it is advisable to be able to have methods that also quantify the rates of processes shown in the table (see Table 5.1).

Other concepts are now being used that have many advantages. These include the notion of land quality and health. In addition it is useful to have some measurements that give an overall index of the state or health of the monitoring site. It is also useful to perform the FAO soil profile descriptions. As explained in the Rangeland Health methodology (see Chapter 4).

Table 5.1 Methods of measuring the different processes or erosion (Credit: Anton Imeson).

Erosion process or factor	Simple monitoring approach method
Splash erosion and creep	Splash cups
	Splash boards
Rainwash by overland flow	A. Rainfall simulator (distilled water or rainfall) Amount of sediment, sediment concentration time to ponding, time to runoff, surface roughness, air entrapment plot characteristics stones vegetation cover, EC and ph
	B. Open plots and gutters, tracers, plot
	C. Closed plots
Surface crusting and slaking	Crust description
	Slaking index
	Dispersion test
	Aggregate stability
	Aggregate size and shape
Erodibility	Soil stability
	Liquid and Plastic limits
	Swelling (Swelling limit, Shrinkage limit)
	Swelling test
Cover	Stones and vegetation
	Protection from shading
Rill erosion	Rill description and measurement
	Mechanical strength and soil moisture
	Air photos
	Continuity of runoff and sinks and sources
Gully erosion	Gully erosion
	Type of gully
Tunnel erosion.	Soil profile characteristics, sodium
	Dispersion and swelling
Soil water retention and storage capacity	Water capacity of the soil
	Soil depth and
	Soil Compaction
	Soil rock fragment and root content

Table 5.1 (*continued*)

Erosion process or factor	Simple monitoring approach method
Soil stability	Pores (stable and unstable)
	Permeability
Runoff and sediment source areas	Rainfall Acceptance:
	Infiltration rate
	Permeability
	Sorptivity
	Patterns in the above in relation to vegetation
Human actions	For example, tillage erosion

5.17 Water resource development irrigation as responses

One of the main strategies for developing dry regions is water development. A major difficulty is that this brings with it great cost and economic sacrifice because the existing water resources are well known and have been use for generations. Economic feasibility is always a consideration, particularly when public money is used and projects tend to be greater than would be the case if local people alone were involved. The evaluation by farmers is crucial because the farmers must also invest money and time and there is always uncertainty about the market conditions. For a government, the impact of irrigated agriculture on the general level of economic activity is a main benefit. The main costs are the development of groundwater resources and irrigation system but there will be other impacts on things such as hydro electric power generation, the navigability of the river, and so on. The main negative impact however, will be in the diminished river flow and the poor quality of the irrigation water return flow. Commercial and sport fishing, as well as recreational activities such as rafting, will also be affected. Such impacts are very common everywhere and many rivers are in a degraded and desertified condition. Fluvial geomorphologists who record the hydrologic geometry of rivers have observed that the average river channel in the United States since the advent of irrigated agriculture has been reduced from about 100 metres to 10 metres during the last century. Water prices do not reflect in any way the real cost of irrigation or water abstraction for cities in dry regions. Often only the private benefits are considered.

Management of aquifers

One of the biggest drivers of desertification is the over exploitation of groundwater so that water levels decline, springs dry up and river channels disappear, carrying water that is 90 per cent effluent. The decision to exploit aquifers is a management problem. One universally agreed approach is that of the safe yield concept. This involves only pumping

the same amount of water that will be replaced by recharge during the next water year. To exploit a greater amount of water is to be participating in mining. However, this is justified because heavy precipitation that occurs once every one or two decades should recharge the aquifer. This ignores the negative impact on the river ecosystem and the other functions. It is also risky because the high rainfall might not occur. There is a great contrast in the risks and management according to whether or not there are laws enacted and regulations that guard against over exploitation.

The key to desertification control and rehabilitation and increased productivity in the Near and Middle East lies in the management of the hydrological cycle (see Arar and Huss 2000).

According to some observations between 1954 and 1975, the desert southern boundary had shifted in the Sudan southwards by 90 to 100 km. Desertification manifests itself in the water logging and salinization of irrigated land, declining water tables and increased groundwater salinity. The main causes of this are poor land and water management at the field level. This has been a recurring problem since ancient times. In many parts of the Near and Middle East, irrigation has provided an initial benefit which was soon lost and farmers' incomes and living standards have dropped as farmers have had to abandon land as it becomes infertile. Any expansion of irrigation faces severe problems of natural salinity in the soils and water. It was estimated that Pakistan is losing 20 000 ha per year as a result of salinity.

Many areas have been recovered by the well-known method of constructing tube wells and draining the soil and leaching the salts and adding gypsum.

In simple hydrogeological situations, changes in the depth of groundwater depth cause an increased head of pressure in an aquifer which causes an increase in discharge at a spring. Groundwater recharge occurs when the amount of rainfall is such that it is enough to infiltrate through the soil and percolate to the groundwater. Percolation may occur very slowly though pores or rapidly along preferential joints or cracks in the rock. When percolating water reaches the groundwater, the water table rises so that there is a change in groundwater depth. This rise also leads to a rise in the groundwater level in valley bottoms or depressions where springs might reappear and rivers might flow again.

Springs can occur where the groundwater table intersects the surface. The disappearance of springs means that there has been less groundwater recharge or increased groundwater withdrawal.

The duration of zero flow in rivers has been used as an indicator of water resource availability in northern China.

5.18 Soil conservation principles and erosion

When planning soil conservation, principles used should be in relation to processes and make use of the adaptive management approach framework. This is probably the best practice for achieving integration of soil conservation measures across scales in space and time. There are several fundamental principles of soil conservation that apply universally. For water erosion by rainwash:

1 Principle: Protecting the soil from the impact force of rain and from the erosive force of wind, for example by using vegetation, plant remains, stones, or mulch. This prevents

crusting, promotes infiltration and fertility as well as the stability and resilience of the soil. *Best practice is to keep vegetation and rock fragment cover above 70 per cent*.

2 Principle: Keep rainfall on the slope, ensure that the soil is managed so that it can retain all water and that there is a high rainfall acceptance rate. Differentiate between different types of runoff generation process. *Best practice is to promote soil structure, soil health, organic matter, shading and manipulate stone and pore size distribution*.

3 Principle: Promote soil resilience. *Best practices avoid herbicides that promote erodibility, promote organic farming, promote heterogeneity (sinks and sources of runoff), reduce evaporation by manipulating soil and using hydrophobicity, stones, etc*.

4 Principle: Promote the depth of rain infiltration and reduce evaporation. *Best practice promotes soil stability, use stones and terra cotta, worms, avoid compaction. Keep in mind that under certain conditions, such as land slide prone slopes, increasing infiltration should be avoided*.

5 Principle: Avoid dispersion of clay which can dramatically lower infiltration rates. *Best practice, manage soil chemistry so that clays are flocculated, monitor soil structure and stability. Make allowance for seasonal differences in soil – water properties and interactions*.

6 Principle: Disturb the soil as little as possible and avoid compaction: *Best practice involves minimum or reduced tillage, avoiding compaction and use of heavy machinery, promoting soil life, not inverting soil profile (allow B or C horizon material on the surface).*

7 Principle: Avoid concentration of runoff water, if there is no erosion-protected (e.g. grassed) water way.

For water erosion by rill, channel and gully erosion:

1 Principle: Rills can form above a compacted subsoil. *Best practice: avoid compaction and don't create macro pores in soil that has a low stability*.

2 Principle: Gullies and rills form by the advance of headcuts. *Best practice: avoid critical conditions of flow with a Froude number above 1; avoid soil crusting and clay dispersion*.

3 Principle: Slopes: The Horton runoff model is only sometimes valid. The USLE says that erosion increases with slope steepness and length. In practice this is only on gently sloping farmland. There is no relationship between slope angle and erosion for slopes steeper than those for which the USLE was developed. *Look at the processes and sinks and sources of runoff and sediment, look for runoff caused by piping, subsurface saturation overland flow and overland flow caused by rapid groundwater rise*.

4 Principle: Manage the sediment balance of the whole catchment and understand the interactions between slopes and river channels. *Dangerous practice: Do not just reduce the amount of sediment entering a channel without evaluating the impact of this on channel erosion or the river might erode its channel and undermine bridges*.

5 Principle: Erosion at seepage points often causes gullies and landslides to occur. *Best practice: Avoid steep long slopes where unsaturated flow-lines converge and saturated areas develop (as on road cuttings). Be aware of the subsoil hydrology*.

5.19 Conceptual approaches to soil conservation

Some of the concepts that are currently being used for soil conservation applications are described here. Concepts are helpful for engaging with stake holders and for motivating and discussing soil conservation actions being taken.

Many conservation scientists have been trained to explain erosion in terms of the different factors responsible. This was the approach of the approach of the US Soil Conservation Service and it is operationalized by means of the Universal Soil Loss Equation (USLE) which considers the factors of rainfall and runoff erosivity, soil erodibility, slope, cover and management.

USLE (Universal Soil Loss Equation)

The USLE approach (also of the Revised USLE) was developed in the 1930s to evaluate and use soil erosion plot data statistically. The equation estimates a theoretical long-term rate of erosion – not the actual amount of erosion caused by an individual storm. It is a management tool. Wischmeier (1976) who developed the approach and was so worried about how it was being applied that he wrote an article entitled the 'Use and misuse of the Universal Soil Loss Equation'. It can be used for soil loss on slopes to demonstrate the possible benefit of conservation farming but the approach is not developed for monitoring nor for use in GIS. The USLE is not suitable for sediment balance or sediment delivery if the aim is management. Within specific contexts it could be helpful as a way of analysing the impact of changes in vegetation cover and rainfall in catchments. In the equation, the vegetation cover (C factor) is by far the most quantitatively important term, and this is why it is often a very practical tool while at the same time the C factor is critical but quite easy to estimate.

There was conceptually a great leap forward when systems paradigms were applied to explain erosion. Dynamic systems models could be developed linking hydrology, vegetation, erosion and land use. These models were developed at first for individual plants and in two dimensions. Gradually, they were used in dynamic GIS, as decision support tools. They could have outputs at different hierarchical levels.

Human impact on key processes

The paradox is that most many of the actions being taken to protect the soil and save biodiversity, although motivated by good intentions, have inadvertent consequences and cause damage to soil functions.

What is vegetated buffer zones?
Retention processes:
• Sedimentation
• Adsorption of P and N to soil
• Uptake of P and N in veg
• Infiltration
• Denitrification

Figure 5.14 Soil erosion is important because it carries phosphates. Buffer strips protect the water because they trap eroded sediment (Credit: SCAPE excursion, Norway and Anton Imeson).

Successful approaches to managing land degradation and erosion at the catchment and river basin scale have taken consideration of the links that exist between problems of erosion and sedimentation on the one hand and the slow changes that are taking place as a result of tectonic movements, on the other. Figure 5.14 shows a soil conservation scientist demonstrating how the successful buffer strip concept is being applied in Norway. They trap sediment and the phosphate adsorbed to it, successfully improving the quality of river and lake water. What is important is the connectivity that exists between the slope and river channel and how this is influenced by people. For a theoretical consideration of this, the conceptual paper by Fryirs *et al*. (2007) is useful as a means of illustrating how the long-term interrelationships between land use change that causes erosion and the long-term movement of sediment through river channels works.

When we consider a river system, then the first approach is to identify the connectivity that exists between the erosion processes on the slope and the river channel. They describe how what are called **buffers, barriers** and **blankets** disrupt the continuity of processes along the river and on the slope, creating systems that have their linkages disrupted. Buffers, barriers and blankets decouple the erosion on the slope from the primary sediment conveyor belt. The authors use this model as a means of interpreting the different responses to rivers that are observed in the field.

What these authors do is to give a **functional** description. This feature maybe thought of as an example of patterns and structures that occur in river channels. Processes that influence the creation of such buffers include mass movements, floods, earthquakes and human activities in the river channels.

When a river is examined, it is evident that the sediment in the flood plain and river channel may have been there for very long indeed. The residence time varies from a few years to millions of years, according to the context. Buffer strips along rivers Figure 5.13

are extremely effective in filtering sediment and phosphates from slope runoff. They have had a very big positive impact in Norway in reducing river contamination. This photograph was taken during an excursion looking at the best practices being used.

Systems approaches and dynamic GIS

Examples of systems based approaches are the many dynamic systems and chaos theory models that show that erosion is sensitive to the initial soil moisture conditions. You can never know the initial soil moisture conditions well enough to know what will happen and be able to predict erosion. In dynamic GIS, models developed by the modellers, erosion and vegetation growth patterns are linked at different scales to economic models and agent based approaches. The problem is that stakeholders are not really able to take advantage of them because the organizations for whom they are developed do not have people who are really able to use them. Institutional frameworks and management are needed to be able to take advantage of them in practice. They enable the effects of land use change to be seen. They might be a good approach to looking at the impact of different soil conservation scenarios on the sediment supply or sediment budgets of large watersheds.

Models such as those mentioned require information about real world hydrological and erosion processes so that these can be parameterized. At the detailed scale, studying the infiltration process using rainfall simulators, open run-off plots, tracers or pattern analysis can be valuable.

Infiltration envelope

The infiltration (envelope) approach pioneered in Israel and America is in many ways very practical and efficient because it enables areas of runoff production to be linked to the intensity-depth-area precipitation data. Different soils respond to erosion and runoff in different ways and this varies seasonally. 'The response of soils to rainfall' approach involves estimating or measuring parameters such as sorptivity, 'time to runoff' and time to 'ponding'. These can be linked to changes in soil structure and to soil chemistry. These approaches have been developed by several research groups in Spain and The Netherlands and elsewhere (see Chapter 3 and Chapter 4).

In this approach, the fundamental concept is that of the 'hydrological or erosion response unit'. It has been found that when erosion occurs in areas that were once sinks (infiltration, accumulation of sediment) are transformed into sources. Sinks and sources occur at different scales. How do soil conservation works affect sediment sinks and sources? This is easy to evaluate with photographs, rainfall simulation and pattern analysis using simple indicators.

Desertification response units and sinks and sources

The sink and source area concept looks at patterns of runoff and sediment production and deposition on slopes and it was described in Chapter 3 and Chapter 4.

Patterns are indicators of processes. If this is known, there is no need to measure discharges; it is enough to monitor patterns. This is a great advantage because fluxes are

in any case sensitive to initial conditions. Potential impacts and risk can be evaluated more accurately and effectively from patterns and structures.

The adaptive management approach places soil conservation within the framework of interacting socio-economic, cultural and bio-physical systems (Chapter 1). There is a state in which no erosion occurs and one in which erosion happens. This involves the interaction between people and their environment. There are state-and-transition-models developed in the USA. It can be shown to the farmer, for example, how his actions affect the processes in ways that result in the system remaining in a healthy state. The adaptive cycle explains the phenomenon of the accumulation release of resources in four distinct stages. Management should be appropriate to the existing stage of the cycle.

Adaptive management response

The adaptive management framework is implicitly being applied to integrate policy, processes in interacting human terms and physical systems.

France is, without specifically using the term, applying the adaptive management approach. French engineers manage the flows of sediment in rivers in a way that takes account of the interactions between hill slope and river channel dynamics over periods of at least 150 years. In Spain, the government and regions have many institutions in place that are responsible for managing sediment and erosion. These include the Government research council organizations and the hydrological services.

Applying an adaptive management framework to soil conservation could save billions of dollars because conservation measures can be tailor-made and geographically explicit. Adaptive management includes treating watersheds as systems in which there are feedbacks between land use, hydrology and sediment transport.

There are many actions that can be taken that improve the resilience of the system and reduce the chance that an area will change from one that is in a non-eroding state to one with a risk of erosion. Mulching with stones and vegetation and improving the soil as a habitat for soil fauna are effective actions that could be taken. Creating shade and heterogeneity are important, as are avoiding compaction and putting subsoil on the surface. Most Europeans have learned to value the cultural and other benefits of non farmed land around cities or elsewhere and the managers have adapted to the requirements of urban people for recreation and experiences in nature. The general response has been to manage forests and natural areas in ways that promote and diversify the functions they provide. With respect to farming there has been a response favoring either organic farming, or more intensive agriculture. The first is often part of a bottom up local economy but associated with high value products, the second to external investments and low value products for supermarkets.

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